

# EXHIBIT 9

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DIGITAL SYSTEMS AND NETWORKS

Digital sections and digital line system – Optical line  
systems for local and access networks

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**Gigabit-capable passive optical networks  
(GPON): General characteristics**

Recommendation ITU-T G.984.1

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## **Recommendation ITU-T G.984.1**

### **Gigabit-capable passive optical networks (GPON): General characteristics**

#### **Summary**

Recommendation ITU-T G.984.1 describes a flexible optical fibre access network capable of supporting the bandwidth requirements of business and residential services and covers systems with nominal line rates of 2.4 Gbit/s in the downstream direction and 1.2 Gbit/s and 2.4 Gbit/s in the upstream direction. Both symmetrical and asymmetrical (upstream/downstream) gigabit-capable passive optical network (GPON) systems are described. This Recommendation proposes the general characteristics for GPON based on operators' service requirements.

#### **Source**

Recommendation ITU-T G.984.1 was approved on 29 March 2008 by ITU-T Study Group 15 (2005-2008) under Recommendation ITU-T A.8 procedure.

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## Recommendation ITU-T G.984.1

### Gigabit-capable passive optical networks (GPON): General characteristics

#### 1 Scope

This Recommendation addresses the general characteristics of gigabit-capable passive optical network (GPON) systems in order to guide and motivate the physical layer and the transmission convergence layer specifications. The general characteristics include examples of services, user-network interfaces (UNIs) and service node interfaces (SNIs) that are requested by network operators. Also, this Recommendation shows the principle deployment configuration.

As much as possible, this Recommendation maintains characteristics from [ITU-T G.982] and ITU-T G.983.x-series Recommendations. This is to promote backward-compatibility with existing optical distribution networks (ODNs) that complies with those Recommendations.

GPON systems are characterized, in general, by an optical line termination (OLT) system and an optical network unit (ONU) or optical network termination (ONT) with a passive optical distribution network (ODN) interconnecting them. There is, in general, a one-to-many relationship between the OLT and the ONU/ONTs, respectively.

#### 2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

- [ITU-T G.652] Recommendation ITU-T G.652 (2003), *Characteristics of a single-mode optical fibre cable*.
- [ITU-T G.808.1] Recommendation ITU-T G.808.1 (2006), *Generic protection switching – Linear trail and subnetwork protection*.
- [ITU-T G.902] Recommendation ITU-T G.902 (1995), *Framework Recommendation on functional access networks (AN) – Architecture and functions, access types, management and service node aspects*.
- [ITU-T G.982] Recommendation ITU-T G.982 (1996), *Optical access networks to support services up to the ISDN primary rate or equivalent bit rates*.
- [ITU-T G.983.1] Recommendation ITU-T G.983.1 (1998), *Broadband optical access systems based on Passive Optical Networks (PON)*.
- [ITU-T G.983.2] Recommendation ITU-T G.983.2 (2002), *ONT management and control interface specification for B-PON*.
- [ITU-T G.983.3] Recommendation ITU-T G.983.3 (2001), *A broadband optical access system with increased service capability by wavelength allocation*.
- [ITU-T G.984.2] Recommendation ITU-T G.984.2 (2003), *Gigabit-capable Passive Optical Networks (GPON): Physical Media Dependent (PMD) layer specification*.
- [ITU-T G.984.3] Recommendation ITU-T G.984.3 (2008), *Gigabit-capable Passive Optical Networks (GPON): Transmission convergence layer specification*.



- [ITU-T G.984.4] Recommendation ITU-T G.984.4 (2008), *Gigabit-capable Passive Optical Networks (GPON): ONT management and control interface specification*.
- [ITU-T G.984.5] Recommendation ITU-T G.984.5 (2007), *Gigabit-capable Passive Optical Networks (GPON): Enhancement band*.
- [ITU-T I.112] Recommendation ITU-T I.112 (1993), *Vocabulary of terms for ISDNs*.

### 3 Definitions

This Recommendation makes frequent use of the terms defined in [ITU-T G.983.1] and [ITU-T G.983.3]; some terms have been added. For convenience, the main definitions related to the GPON service requirements are reported in this clause.

#### 3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

**3.1.1 service node interface (SNI):** [ITU-T G.902]

**3.1.2 user-network interface (UNI):** [ITU-T I.112]

#### 3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

**3.2.1 adaptation function (AF):** AF is additional equipment and/or function to change an ONT/ONU subscriber-side interface into the UNI. Functions of AF depend on the ONT/ONU subscriber-side interface and UNI interface. AF is also used to change an OLT network interface into the SNI interface that is required by an operator.

**3.2.2 differential fibre distance:** An OLT is connected to several ONU/ONTs. The differential fibre distance is the difference in the distance between the nearest and furthest ONU/ONT from the OLT.

**3.2.3 logical reach:** Logical reach is defined as the maximum distance that can be achieved for a particular transmission system, regardless of the optical budget.

**3.2.4 mean signal transfer delay:** The mean signal transfer delay is the average of the upstream and downstream delay values between reference points; this value is determined by measuring round-trip delay and then dividing by 2.

**3.2.5 optical access network (OAN):** The OAN is the set of access links sharing the same network-side interfaces and supported by optical access transmission systems. The OAN may include a number of ODNs connected to the same OLT.

**3.2.6 optical distribution network (ODN):** In the PON context, a tree of optical fibres in the access network, supplemented with power or wavelength splitters, filters or other passive optical devices.

**3.2.7 optical line termination (OLT):** A device that terminates the common (root) endpoint of an ODN, implements a PON protocol, such as that defined by [ITU-T G.984], and adapts PON PDUs for uplink communications over the provider service interface. The OLT provides management and maintenance functions for the subtended ODN and ONUs.

**3.2.8 optical network termination (ONT):** A single subscriber device that terminates any one of the distributed (leaf) endpoints of an ODN, implements a PON protocol, and adapts PON PDUs to subscriber service interfaces. An ONT is a special case of an ONU.

**3.2.9 optical network unit (ONU):** A generic term denoting a device that terminates any one of the distributed (leaf) endpoints of an ODN, implements a PON protocol, and adapts PON PDUs to subscriber service interfaces. In some contexts, an ONU implies a multiple-subscriber device.

**3.2.10 physical reach:** Physical reach is defined as the maximum physical distance that can be achieved for a particular transmission system.

**3.2.11 service:** Service is defined as a network service required by operators. Service is described by a name that is clearly recognized by everyone, regardless of whether it is a frame structure name or a general name.

## 4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

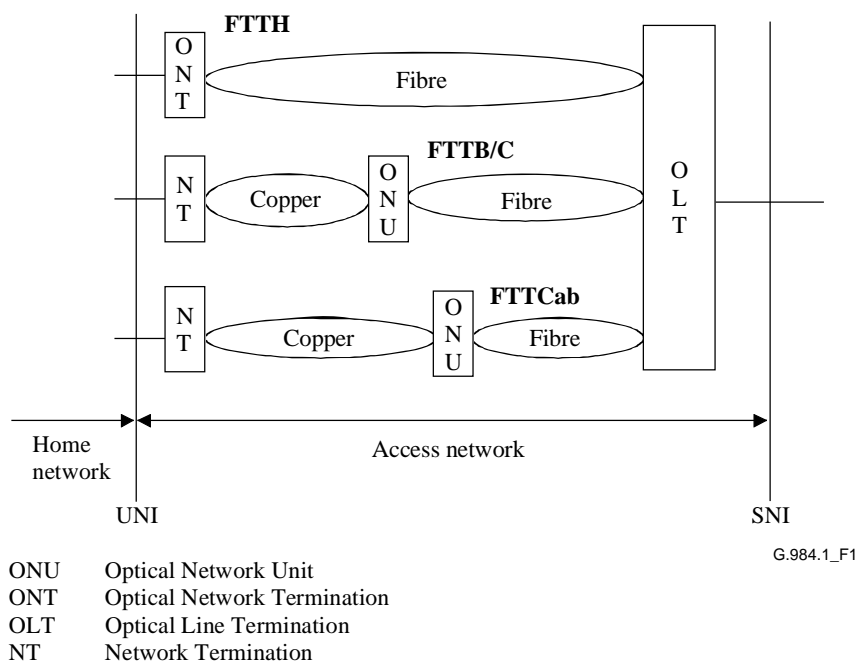
AF	Adaptation Function
BRI	Basic Rate Interface
DSL	Digital Subscriber Line
FTTB	Fibre to the Building
FTTC	Fibre to the Curb
FTTCab	Fibre to the Cabinet
FTTH	Fibre to the Home
ISDN	Integrated Services Digital Network
LT	Line Terminal
MDU	Multi-Dwelling Unit
NT	Network Termination
OAM	Operation, Administration and Maintenance
OAN	Optical Access Network
ODN	Optical Distribution Network
OLT	Optical Line Termination
ONT	Optical Network Termination
ONU	Optical Network Unit
OpS	Operations System
PDH	Plesiochronous Digital Hierarchy
PON	Passive Optical Network
POTS	Plain Old Telephone Service
PRI	Primary Rate Interface
PSTN	Public Switched Telephone Network
SDH	Synchronous Digital Hierarchy
SN	Serial Number
SNI	Service Node Interface
TC	Transmission Convergence

UNI	User-Network Interface
VOD	Video On Demand
WDM	Wavelength Division Multiplexing

## 5 Architecture of the optical access network

### 5.1 Network architecture

The optical section of a local access network system can be either active or passive and its architecture can be either point-to-point or point-to-multipoint. Figure 1 shows the architectures considered, which range from fibre to the home (FTTH), through fibre to the building/curb (FTTB/C) to fibre to the cabinet (FTTCab). The optical access network (OAN) is common to all architectures shown in Figure 1, hence the commonality of this system has the potential to generate large worldwide volumes.



**Figure 1 – Network architecture**

The differences of the FTTB, FTTC, FTTCab and FTTH network options are mainly due the different services supported, so they can be treated the same in this Recommendation.

#### 5.1.1 FTTB scenario

The FTTB scenario is divided into two scenarios, one for multi-dwelling units (MDUs) and the other for businesses. Each scenario has the following service categories.

##### 5.1.1.1 FTTB for MDU

- Asymmetric broadband services (e.g., digital broadcast services, VOD, file download, etc.).
- Symmetric broadband services (e.g., content broadcast, e-mail, file exchange, distance learning, telemedicine, online-gaming, etc.).
- POTS and ISDN. The access network must be able to provide, in a flexible way, narrow-band telephone services with appropriate timing for the introduction.

**5.1.1.2 FTTB for business**

- Symmetric broadband services (e.g., group software, content broadcast, e-mail, file exchange, etc.).
- POTS and ISDN. The access network must be able to provide, in a flexible way, narrow-band telephone services with the appropriate timing for the introduction.
- Private line services. The access network must be able to provide, in a flexible way, private line services at several rates.

**5.1.2 FTTC and FTTCab scenario**

Within this scenario, the following service categories have been considered:

- Asymmetric broadband services (e.g., digital broadcast services, VOD, file download, online-gaming, etc.).
- Symmetric broadband services (e.g., content broadcast, e-mail, file exchange, distance learning, telemedicine, etc.).
- POTS and ISDN. The access network must be able to provide, in a flexible way, narrow-band telephone services with the appropriate timing for the introduction.
- xDSL backhaul.

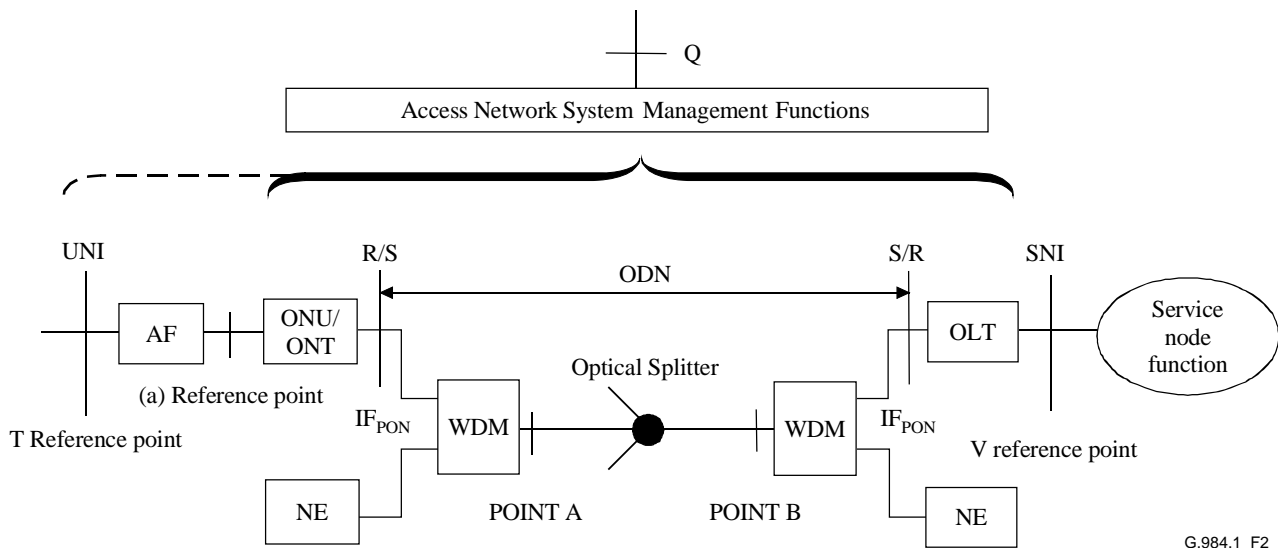
**5.1.3 FTTH scenario**

Within this scenario, the following service categories have been considered:

- Asymmetric broadband services (e.g., digital broadcast services, VOD, file download, etc.).
- Symmetric broadband services (e.g., content broadcast, e-mail, file exchange, distance learning, telemedicine, online-gaming, etc.).
- POTS and ISDN. The access network must be able to provide, in a flexible way, narrow-band telephone services with the appropriate timing for the introduction.

**5.2 Reference configuration**

The reference configuration is shown in Figure 2.



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ONU	Optical Network Unit
ONT	Optical Network Terminal
ODN	Optical Distribution Network
OLT	Optical Line Termination
WDM	Wavelength Division Multiplex Module (If WDM is not used, this function is not necessary.)
NE	Network Element which uses the different wavelength from the OLT and the ONU
AF	Adaptation Function (Sometimes, it may be included in the ONU.)
SNI	Service Node Interface
UNI	User Network Interface
S	Point on the optical fibre just after the OLT (Downstream)/ONU (Upstream) optical connection point (i.e., optical connector or optical splice)
R	Point on the optical fibre just before the ONU (Downstream)/OLT (Upstream) optical connection point (i.e., optical connector or optical splice)
(a) Reference point	If AF is included in the ONU, this point is not necessary.
POINT A/B	If WDM is not used, these points are not necessary.

NOTE – Whether or not the AF is an operating object of the Q interface depends on the service.

### Figure 2 – Reference configuration for GPON

### 5.2.1 Service node interface

See [ITU-T G.902].

### 5.2.2 Interface at the reference points S/R and R/S

The interface at reference points S/R and R/S is defined as IF<sub>PON</sub>. This is a PON-specific interface that supports all the protocol elements necessary to allow transmission between OLT and ONUs.

## 6 Services, user-network interface and service node interface

## 6.1 Services

GPON is required to support all currently known services and new services being discussed for residential subscribers and business customers, because of such a broadband capability.

What specific services should be provided is clearer to some operators than to others and depends heavily on the particular regulatory conditions of each operator's markets, as well as on the market's own potential. How these services are delivered in a cost-effective way is a function not only of legal conditions, but also of factors including existing telecommunication infrastructure, dwelling distribution, and residential and business customers mix.

Some examples of services are described in clause I.1.

## **6.2 User-network interface (UNI) and service node interface (SNI)**

ONU/ONT has UNI, as well as OLT, has an SNI as described in Figure 2. UNI/SNI depends on which services are provided by the service operator.

Some examples of UNI are described in clause I.2 and examples of SNI are described in clause I.3.

## **7 Bit rate**

Basically, GPON aims at transmission speeds greater than or equal to 1.2 Gbit/s. Accordingly, GPON identifies two transmission speed combinations as follows:

- 1.2 Gbit/s up, 2.4 Gbit/s down;
- 2.4 Gbit/s up, 2.4 Gbit/s down.

The most important bit rate is 1.2 Gbit/s up, 2.4 Gbit/s down, constituting nearly all of the deployed and planned deployment of the GPON systems.

## **8 Logical reach**

Logical reach is the maximum distance between ONU/ONT and OLT except for the limitation of the physical layer. In GPON, the maximum logical reach is defined as 60 km.

## **9 Physical reach**

Physical reach is the maximum physical distance between the ONU/ONT and the OLT. In GPON, two options are defined for the physical reach: 10 km and 20 km. It is assumed that 10 km is the maximum distance over which FP-LD can be used in the ONU for high bit rates such as 1.25 Gbit/s or above.

## **10 Differential fibre distance**

In GPON, the maximum differential fibre distance is 20 km. This affects the size of the ranging window and provides compliance with [ITU-T G.983.1].

## **11 Maximum mean signal transfer delay**

GPON must accommodate services that require a maximum mean signal transfer delay of 1.5 ms.

Specifically, GPON system must have a maximum mean signal transfer delay time of less than 1.5 ms between T-V (or (a)-V, depending on the operator's preference). See clause 12 of [ITU-T G.982]. Delays introduced by the adaptation functions such as circuit emulation are not included in this value.

Although a section of the delay measurement is T-V for FTTH system, or (a)-V for the other application in [ITU-T G.982], in a GPON system the reference points are not restricted by the system configuration.

## **12 Split ratio**

Basically, the larger the split ratio is for GPON, the more attractive it is for operators. However, a larger split ratio implies greater optical splitting which creates the need for an increased power budget to support the physical reach.

Split ratios of up to 1:64 are realistic for the physical layer, given current technology. However, anticipating the continued evolution of optical modules, the TC layer must consider split ratios up to 1:128.

### 13 Service overlay

An overlay wavelength may be used to provide enhanced services to the subscriber. Accordingly, GPON must vacate the Enhancement Band defined in [ITU-T G.983.3].

### 14 Protection on the PON section

From the viewpoint of administration of the access network, the protection architecture of GPON is considered to enhance the reliability of the access networks. However, protection shall be considered as an optional mechanism because its implementation depends on the realization of economical systems. Further information on protection switching can be found in [ITU-T G.808.1].

This clause presents some possible duplex configurations and related requirements as examples of protected GPON systems. In addition, the required OAM message for protection is mentioned.

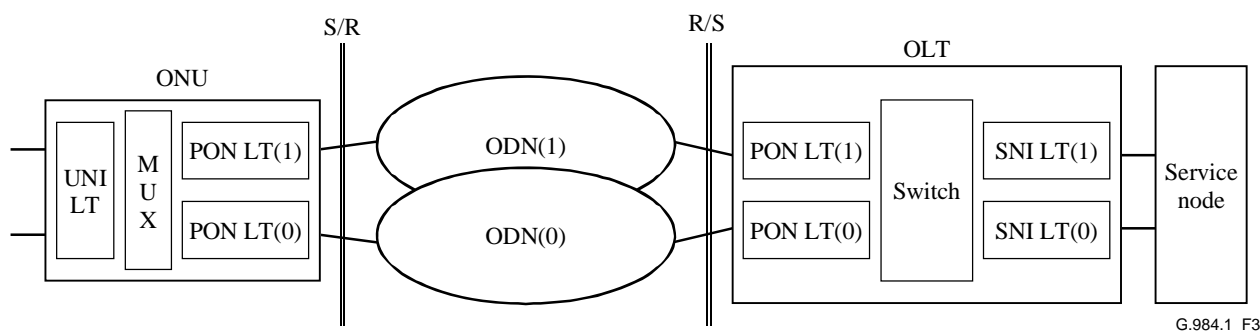
#### 14.1 Possible switching types

There are two types of protection switching, both of which are analogous to those of SDH systems:

- i) automatic switching; and
- ii) forced switching.

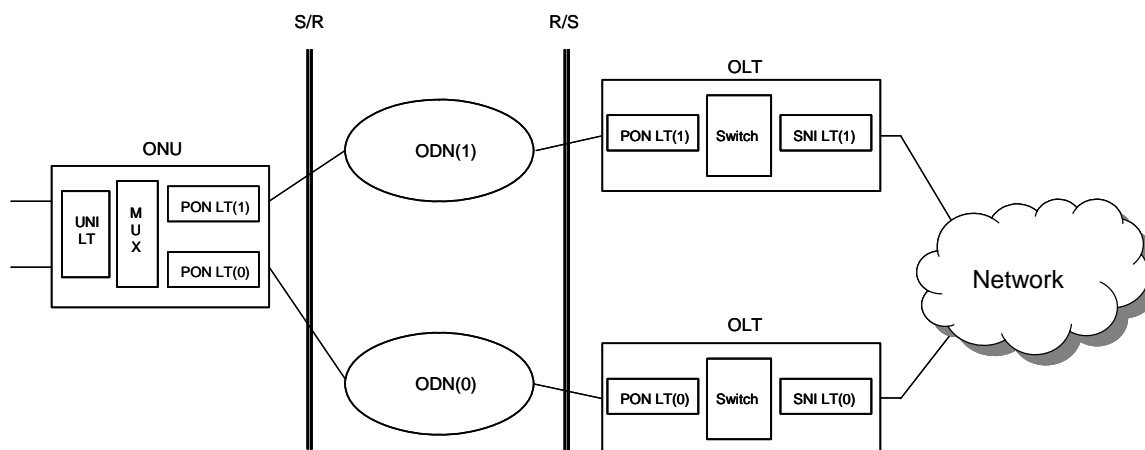
The first type is triggered by fault detection, such as loss of signal, loss of frame, signal degrade (BER becomes worse than the predetermined threshold), and so on. The second type is activated by administrative events, such as fibre rerouting, fibre replacement, etc. Both types should be possible in a GPON system, if required, even though they are optional functions. The switching mechanism is generally realized by the OAM function, therefore, the required OAM information field should be reserved in the OAM frame.

Figure 3a shows the self-contained duplex system model for the access network. The relevant part of the protection in the GPON system in this scheme should be a part of the protection between the ODN interface in the OLT and the ODN interface in the ONU via the ODN, excluding the SNI redundancy in the OLT.



**Figure 3a – Duplex system model**

Figure 3b shows the duplex system model for the dual-parented access network. The relevant part of the protection in the GPON system should be a part of the protection between the ODN interface in the ONU and each ODN interface in the two OLTs via the ODN, plus the signalling required to implement protection functions upstream from the SNI.



**Figure 3b – Dual-parented duplex system model**

## 14.2 Possible duplex GPON configurations and characteristics

There can be several types of duplex GPON systems, as shown in Figures 4a and 4b. The control protocols for each configuration should be specified independently from one another.

For example, in Figure 4b, no switching protocol is required since the switching is carried out only in the OLT.

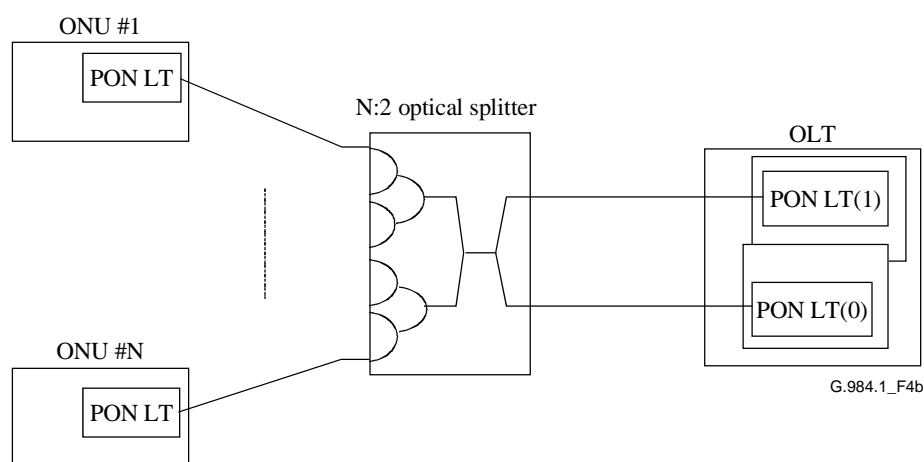
### 14.2.1 Configuration examples

Type A: A deprecated configuration that duplicated only the optical fibres.

Type B: The second configuration (Figure 4a) doubles the OLTs and the optical fibres between the OLTs and the optical splitter, and the splitter has two input/output ports on the OLT side. This configuration reduces the cost of duplexing the ONUs, although only the OLT side can be recovered.

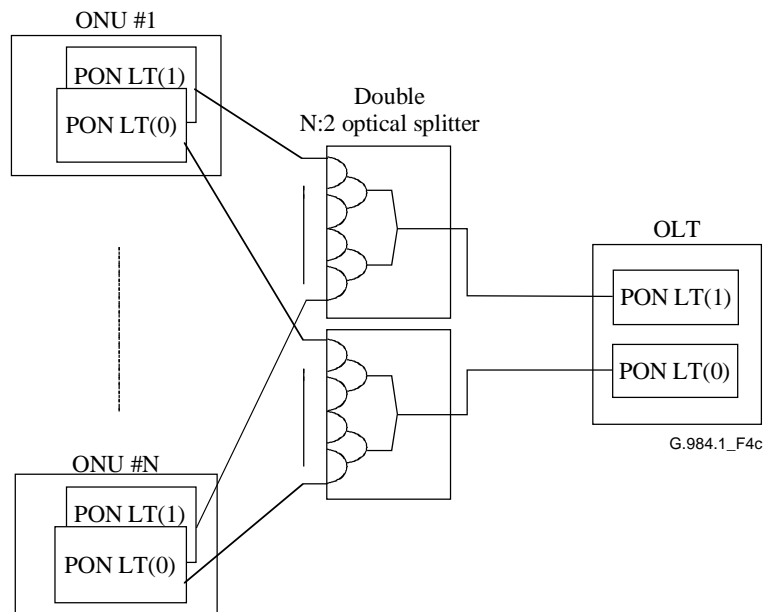
Type C: The third configuration (Figure 4b) doubles not only the OLT side facilities but also the ONU side. In this configuration, recovery from failure at any point is possible by switching to the standby facilities. Therefore, the full duplex cost enables high reliability.

Type D: A deprecated configuration that allowed the mixing of duplicated and non-duplicated ONUs, essentially providing a combination of types B and C protection.



**Figure 4a – Duplex GPON system: OLT-only duplex system**





**Figure 4b – Duplex GPON system: Full duplex system**

Note that in both of these types of protection schemes, the PON line terminations do not need to reside in a single OLT equipment. In fact, they may be located in physically diverse locations (dual parenting). The control of such a system is discussed in Appendix III.

#### 14.2.2 Characteristics

Type B: This configuration requires cold standby of the spare circuit in the OLT side. In this case, signal loss or even frame loss is, in general, inevitable in the switching period. However, all the connections supported between the service node and the terminal equipment should be held after this switching.

Type C: In this case, the hot standby of the spare receiver circuits is possible in both ONU and OLT sides. In addition, hitless switching (without frame loss) is also possible in this configuration.

#### 14.3 Requirements

- 1) The protection switching function should be optional.
- 2) Both automatic protection switching and forced switching are possible in the GPON system, if required, even though they are optional functions.
- 3) All the configuration examples of clause 14.2 will be possible, even though they are optional functions.
- 4) The switching mechanism is generally realized by the OAM function, therefore, the required OAM information field must be reserved in the OAM frame.
- 5) All the connections supported between the service node and the terminal equipment should be held after switching.

Regarding the last requirement, one implementation of the POTS service node (exchange) requires the frame loss period to be less than 120 ms. If the frame loss period becomes longer than that, the service node disconnects the call, and the call set-up is required again after the protection switching. Since GPON supports the emulation of conventional services, such as POTS and ISDN, this value should be taken into consideration.

T1 and E1 services require 50 ms protection times, so for these services to be provided as protected, the GPON should support 50 ms protection times.

#### **14.4 Required information fields for OAM frame**

Protection switching requires less than ten codes to be used for both upstream and downstream, which will be realized by the field of the OAM frame. The field mapping of the OAM frame for the protection will be required to be defined.

#### **15 Security**

Due to the multicast nature of the PON, GPON needs a security mechanism adapting the following requirements:

- To prevent other users from easily decoding the downstream data.
- To prevent other users from masquerading as another ONU/ONT or user.
- To allow cost-effective implementation.

## Appendix I

### Examples of GPON services, architectures and service protocol stacks

(This appendix does not form an integral part of this Recommendation)

This appendix provides various examples of practical GPON system aspects. First, a review of the typical services a GPON system supports is given. Second, a selection of system architectures are illustrated. Third, the common protocol stack traces are laid out for all these services and systems.

It should be noted that since GPON is so widely applicable, the total scope of all the variants is very large, and any single implementation will not implement all of the possible features. The object of this appendix is to only give a general overview for the family of systems.

#### I.1 Services, UNIs and SNIs

This clause describes some examples of services, UNI and SNI, which are required by operators.

##### I.1.1 Examples of services

Some examples of services that GPON are required to support are shown in Table I.1, along with relevant remarks.

**Table I.1 – Examples of services and related remarks**

Service category (Note 1)	Service	Remarks
Data service	Ethernet (Note 2)	Standardized in [b-IEEE 802.3]. Comply with [b-IEEE 802.1D].
PSTN	POTS	Mean signal transfer delay time between T-V (or (a)-V) should be less than 1.5 ms. If echo cancellation is used in the network, the mean signal transfer delay time between T-V (or (a)-V) on the PON-based system may be longer, provided end-to-end transfer delay requirements are met.  Synchronize with the network clock (Note 3). Signal on the T reference point and V reference point must be continuous.
	ISDN (BRI)	Bearer rate is 144 kbit/s. Mean signal transfer delay time between T-V (or (a)-V) should be less than 1.5 ms. Synchronize with the network clock (Note 3).
	ISDN (PRI)	Bearer rate is 1.544 Mbit/s and 2.048 Mbit/s. Mean signal transfer delay time between T-V (or (a)-V) should be less than 1.5 ms. Synchronize with the network clock (Note 3).
Private Line	T1	Bearer rate is 1.544 Mbit/s. Mean signal transfer delay time between T-V (or (a)-V) should be less than 1.5 ms.
	E1	Bearer rate is 2.048 Mbit/s. Mean signal transfer delay time between T-V (or (a)-V) should be less than 1.5 ms.

**Table I.1 – Examples of services and related remarks**

<b>Service category (Note 1)</b>	<b>Service</b>	<b>Remarks</b>
	DS3	Bearer rate is 44.736 Mbit/s.
	E3	Bearer rate is 34.368 Mbit/s.
Video	Digital video	Primary focus is on video over IP, with a QoS sufficient to support competitive viewing experience as compared to traditional transport methods.
<p>NOTE 1 – Service category is merely an index. It is not meaningful in itself, but it is useful in visualizing the services.</p> <p>NOTE 2 – Ethernet service is mainly to transmit data such as IP, which includes VoIP, video streams coded by MPEG-2 or MPEG-4, and so on.</p> <p>NOTE 3 – See [b-ITU-T G.810], [b-ITU-T G.813], [b-ITU-T G.8261], [b-ITU-T G.703] and [b-ITU-T G.8262].</p>		

**I.1.2 Examples of UNI**

In this appendix, UNI is defined as the interface that includes the following conditions:

- described by a well-known standard;
- includes a physical layer aspect.

Some UNIs are provided via an AF, so it is not mandatory that the ONU/ONT support those interfaces.

Examples of UNIs, physical interfaces and services that they provide are shown in Table I.2.

**Table I.2 – Examples of UNI and services**

<b>UNI (Note 1)</b>	<b>Physical interface (Note 2)</b>	<b>Service (Note 3)</b>
10BASE-T ([b-IEEE 802.3])	–	Ethernet
100BASE-TX ([b-IEEE 802.3])	–	Ethernet
1000BASE-T ([b-IEEE 802.3])	–	Ethernet
[b-ITU-T I.430]	–	ISDN (BRI)
[b-ITU-T G.703]	PDH	DS3, ATM, E1, E3
[b-ANSI T1.102], [b-ANSI T1.107]	PDH	T1, DS3
<p>NOTE 1 – There are many other services accommodated in GPON, but those services do not have specified UNIs.</p> <p>NOTE 2 – Each item in the "physical interface" column is illustrated by the corresponding entry in the "UNI" column.</p> <p>NOTE 3 – The column labelled "service" shows which services can be supported by the physical interface.</p>		

**I.1.3 Examples of SNI**

In this appendix, SNI is defined as the interface that includes the following conditions:

- described by a well-known standard;
- includes a physical layer aspect.

Examples of SNIs, physical interfaces and services that they provide are shown in Table I.3.

**Table I.3 – Examples of SNI and services**

<b>SNI (Note 1)</b>	<b>Physical interface (Note 2)</b>	<b>Service (Note 3)</b>
1000BASE ([b-IEEE 802.3]) 10000BASE ([b-IEEE 802.3])	–	Ethernet
[b-ITU-T G.965]	V5.2	POTS, ISDN(BRI), ISDN(PRI)
[b-ITU-T G.703]	PDH, STM-1e	DS3, ATM, E1, E3, STM-1, DS1
[b-ITU-T G.957]	STM-1, 4, 16	E1, E3, DS1, DS3, GFP, E4, STM-n, ATM
[b-ANSI T1.107]	PDH	DS1, DS3
[b-ANSI T1.105.06] [b-ANSI T1.117]	OC3, OC12	DS1, DS3, ATM

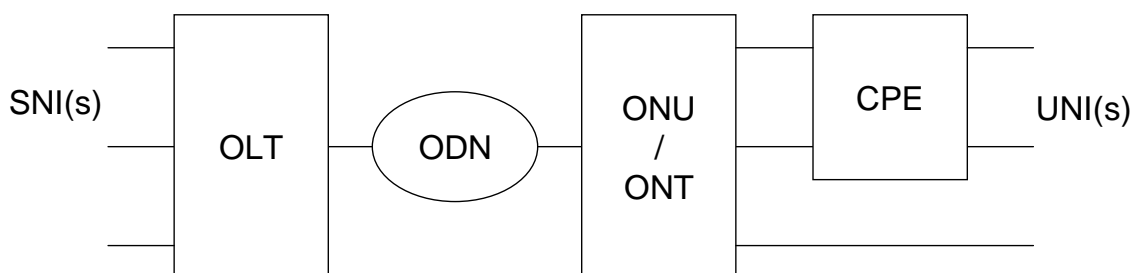
NOTE 1 – There are many other services accommodated in GPON, but those services do not have specified SNIs.

NOTE 2 – Each item in the "physical interface" column is illustrated by the corresponding entry in the "SNI" column.

NOTE 3 – The column labelled "service" shows which services can be supported by the physical interface.

## I.2 Typical system architectures

Figure I.1 shows a generic GPON system. This is developed more specifically in Figures I.2 to I.7.

**Figure I.1 – Generic GPON system**

### I.2.1 OLT variants

Figure I.2 shows a pure-OLT option. In this case, the OLT equipment contains only the GPON adaptation function, and typically (but not necessarily) some level of Ethernet aggregation function. It is the simplest form of OLT, and avoids as many specific service linkages as possible.

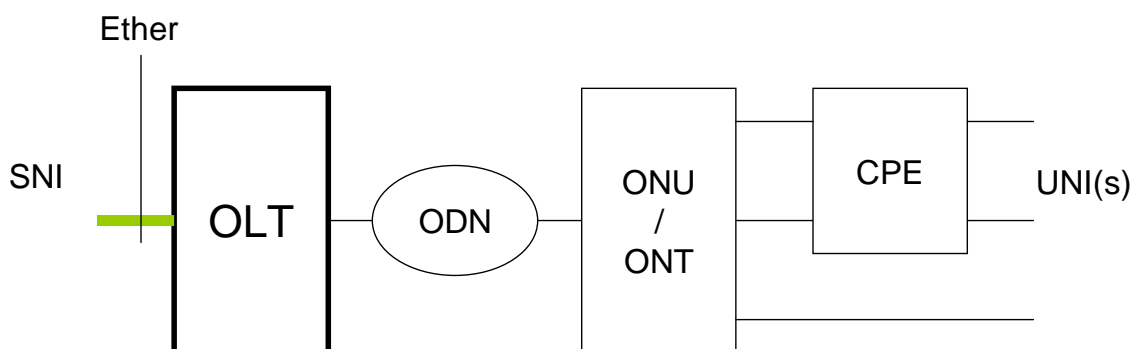
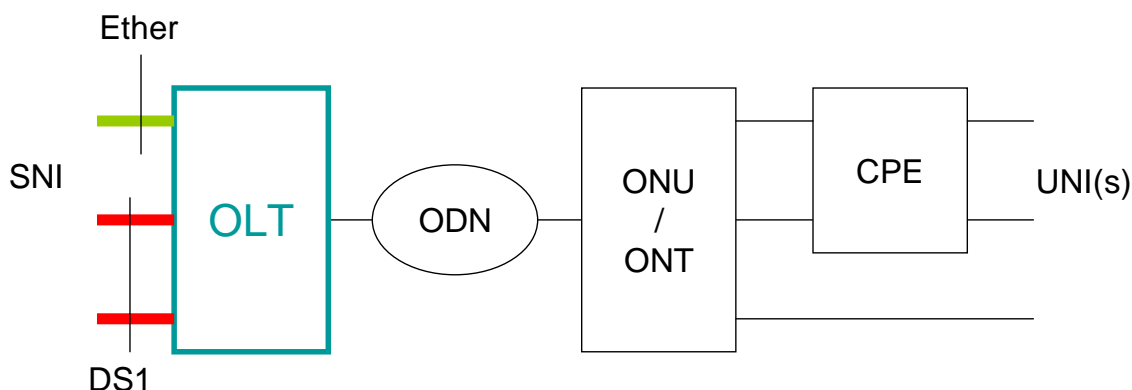
**Figure I.2 – Pure OLT scenario**

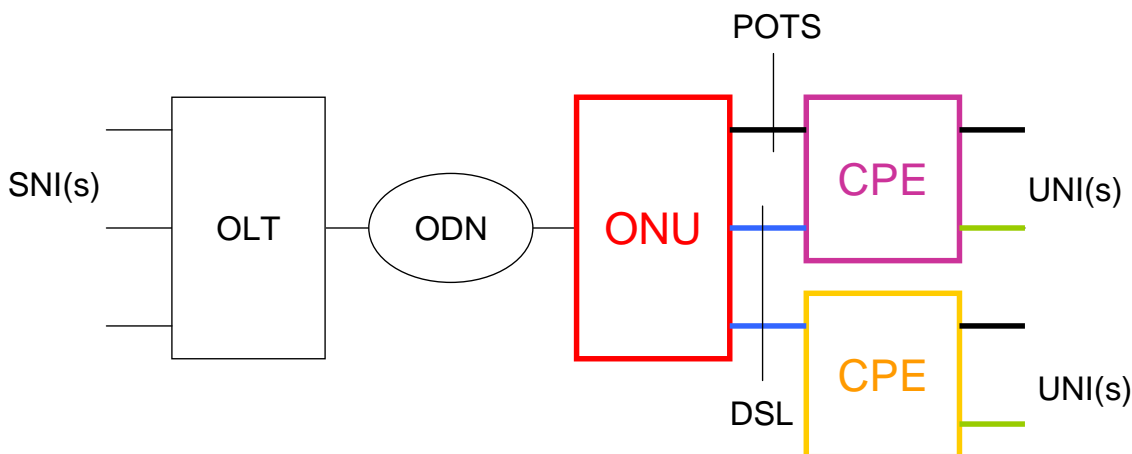
Figure I.3 shows a grooming OLT scenario. In this case, the OLT takes on additional service-grooming functions, typically including voice gateway and TDM circuit emulation functions. Note that these services can be provided using a 'pure OLT' and a separate voice gateway; however, as a practical matter, the integration of voice and TDM services seems to have strong economic and practical advantages.



**Figure I.3 – Grooming OLT scenario**

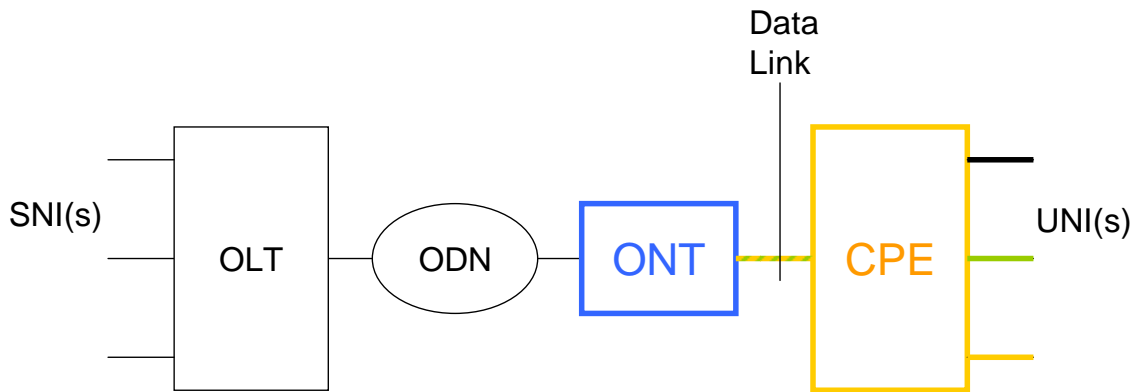
### I.2.2 ONU variants

Figure I.4 shows the 'VDSL/POTS ONU' variant. The distinguishing feature of this variation is that the ONU is used to create copper-based interfaces just like a digital loop carrier/digital subscriber line access multiplexer (DLC/DSLAM) would do. There are two sub-types of this scheme. The first is where the ONU provides both POTS and VDSL interfaces to the customer, trying to centralize functions and reduce the need for CPE. The second is where the ONU provides VDSL-only interfaces, trying to minimize the ONU's size and power, albeit at the cost of requiring POTS derivation at the CPE. This alternative is useful mostly in FTTB and FTTC applications.



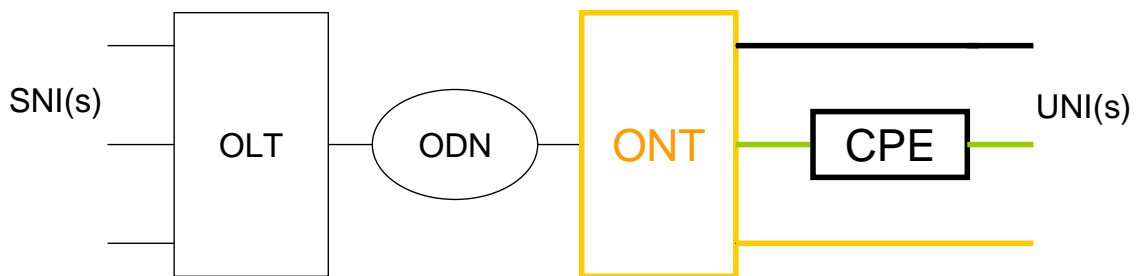
**Figure I.4 – VDSL/POTS ONU scenario**

Figure I.5 shows the 'GPON modem' variant, where the ONT is made as small and simple as possible. In this case, it resembles a modem that provides Layer 1 and 2 interworking between the GPON optical interface and the data link technology. The data link then carries all service flows to the CPE, which does the bulk of the service interworking function. The popular data link technologies in use today are CAT5-based Ethernet, HPNA-over-coax and MoCA. This system is mostly used in FTTH applications.



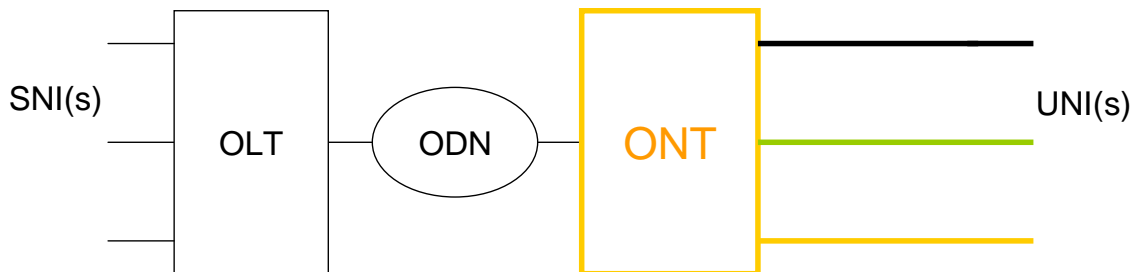
**Figure I.5 – GPON modem scenario**

Figure I.6 shows the 'integrated ONT' situation. This can be thought of as the merger of the GPON modem and the service-deriving CPE in the previous diagram. However, this merging of functions has critical implications on which system is responsible for the management of the services. It should also be noted that even though significant functions have been incorporated into the ONT, a CPE is typically still placed in the home. This scenario is also popular for FTTH.



**Figure I.6 – Integrated ONT scenario**

Figure I.7 shows the 'residential gateway ONT' situation. This can be thought of as the merger of the integrated ONT and the service-deriving CPE in the previous diagram. This draws Layer 3 functionality into the ONT, including such items as routing, NAT and firewall functionality. This scenario is also popular for FTTH.



**Figure I.7 – Residential gateway ONT scenario**

### **I.3 Service protocol stacks**

The following clauses present a listing of protocol stacks for the important service traces in GPON systems. By service, we mean the basic Layer 2-3 interfaces that have a major impact on the GPON equipment. Many high-layer services can ride on top of these interfaces; however, they tend not to

have such a concrete impact on the GPON equipment, or at least not an impact any different than any other access system.

### **I.3.1 Common functions**

The common GPON layers are shown in Figure I.8. [ITU-T G.984.2] specifies the GPON physical medium and the physical medium dependents (optics). [ITU-T G.984.4] defines the transmission convergence layer, which deals primarily with the construction of the transmission frame and the encapsulation of payload datagrams inside GPON encapsulation method (GEM) fragments. There is a wealth of other auxiliary features described in [ITU-T G.984.3], including the PLOAM channel, dynamic bandwidth allocation, and the PON-level QoS frameworks, that are possible.

It should be noted that the DBA algorithm is not specified in any standard, but this is not an interoperability issue, and the non-specification has been intentional.

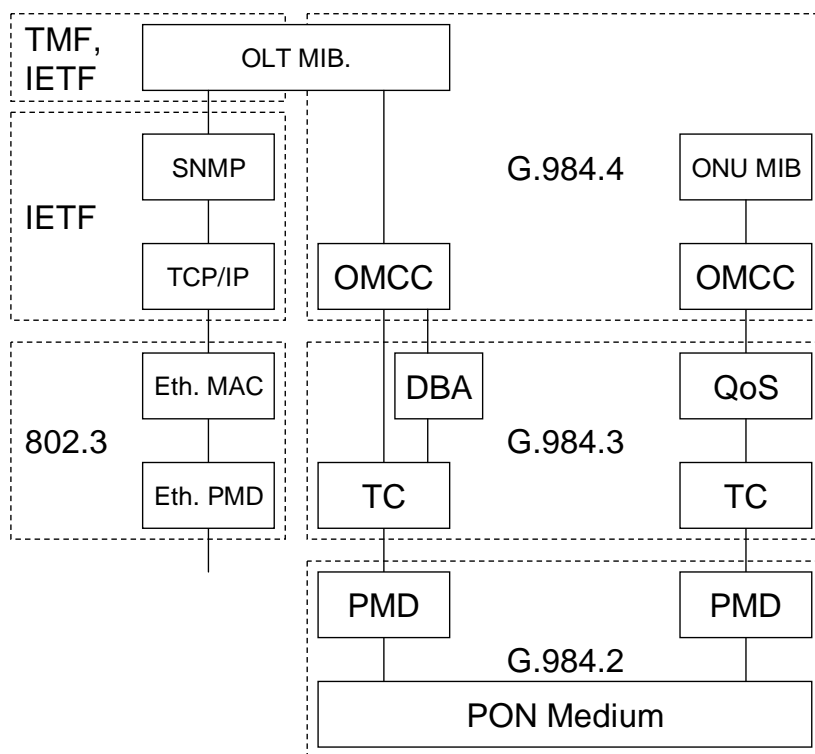
The QoS system in GPON defines a scheme where each ONT may contain one or more transmission container(s) (T-CONTs). Each T-CONT may contain one or more GEM ports, which are the smallest connection that GPON systems handle. [ITU-T G.984.3] leaves the arrangement of T-CONT and GEM ports open. The mainstream arrangement is four service-bearing T-CONTs per ONT, with each representing a different class of service.

[ITU-T G.984.4] defines the ONT management and configuration interface (OMCI). It defines both a management information base (MIB) for all the functions controlled in the ONT, as well as the ONT management communication channel (OMCC) that provides all the mechanisms required for the OLT to provide FCAPS functionality for the ONT.

The OLT management is a somewhat more complex object. It contains by proxy all the MIBs of all the ONUs supported by that OLT, as well as all the other MIBs that describe the other functions in the OLT. This MIB is defined by several standards groups, including the Internet Engineering Task Force (IETF) and the TM forum. Typically, these MIBs are accessed using standard IETF-defined protocols (SNMP over TCP/IP). Most OLTs provide a dedicated Ethernet interface for this management traffic.

All of the functions mentioned above are common functions, involved in all of the service traces that follow. They will be more compactly represented in the later diagrams for the sake of brevity.

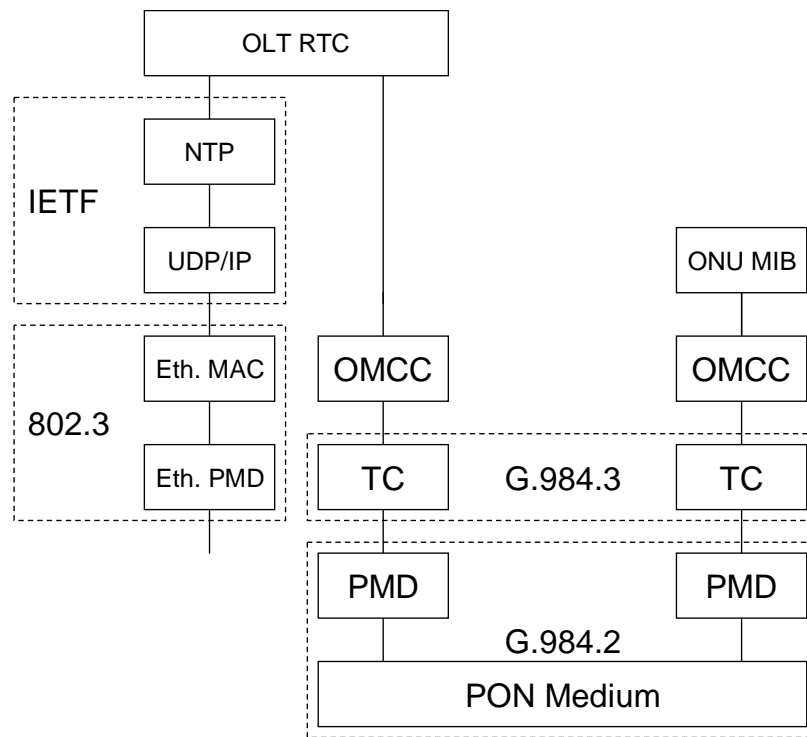




**Figure I.8 – GPON common functions**

The GPON real-time clock service is shown in Figure I.9. The OLT receives real-time clock data via NTP, typically over an Ethernet interface via UDP over IP. The OLT thereby maintains its own internal RTC, which it uses to timestamp all manner of event data.

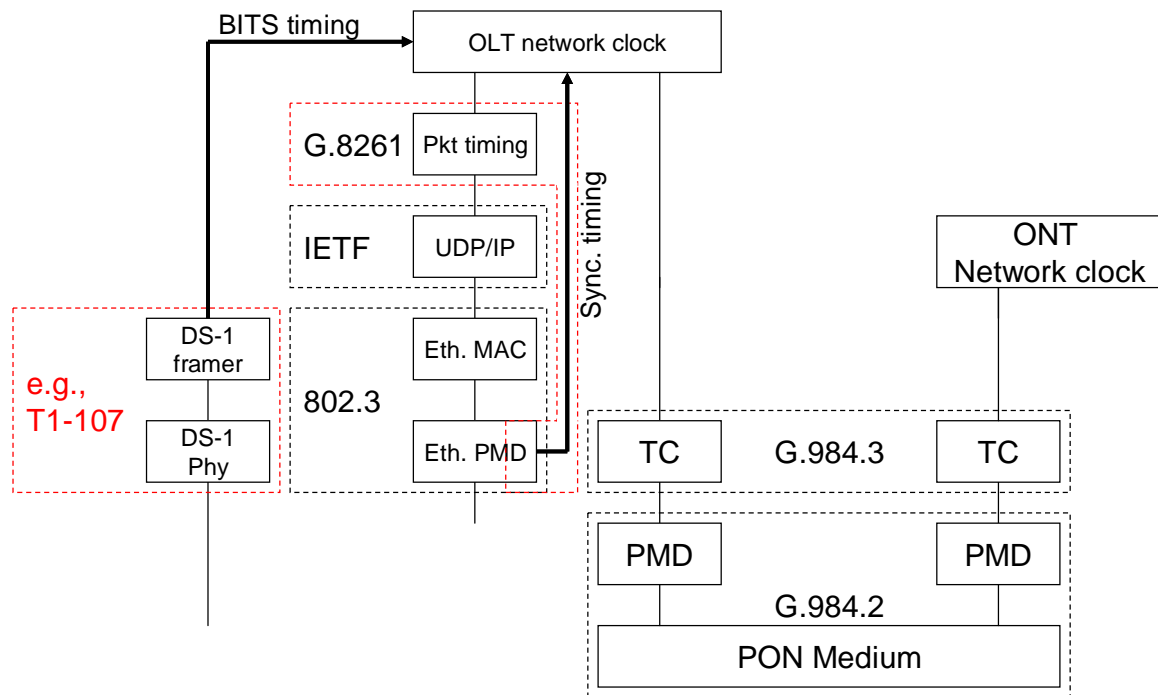
The ONT does not extend this RTC. Rather, its performance-monitoring and event-collection processes are synchronized with those of the OLT via the OMCI. The OLT routinely collects all of this data every 15 minutes and logs it with the OLT RTC.



**Figure I.9 – Real-time clock service**

The GPON network clock scheme is shown in Figure I.10. The OLT needs to obtain a high quality traceable timing clock, which serves as the master for all GPON interface timing. The normal source for the OLT's clock is a BITS timing input. However, in cases where a BITS source is not available, then an alternative method is needed. The alternative could be synchronous line timing from an SNI that is traceable to the network clock, or packet-based timing.

Once the OLT network clock is established, it is used to source timing to the GPON interfaces, which in turn distribute timing to the counterpart ONT GPON interfaces. The ONT equipment then obtains its network clock from the GPON interface. This timing signal is ideal for TDM service interworking functions that are integrated into the ONT. Typically, this timing signal is not available to terminal adapters. However, if the timing signal is provided to the terminal adapters, then the synchronous Ethernet method is preferred.



**Figure I.10 – Network clock service**

### I.3.2 Data functions

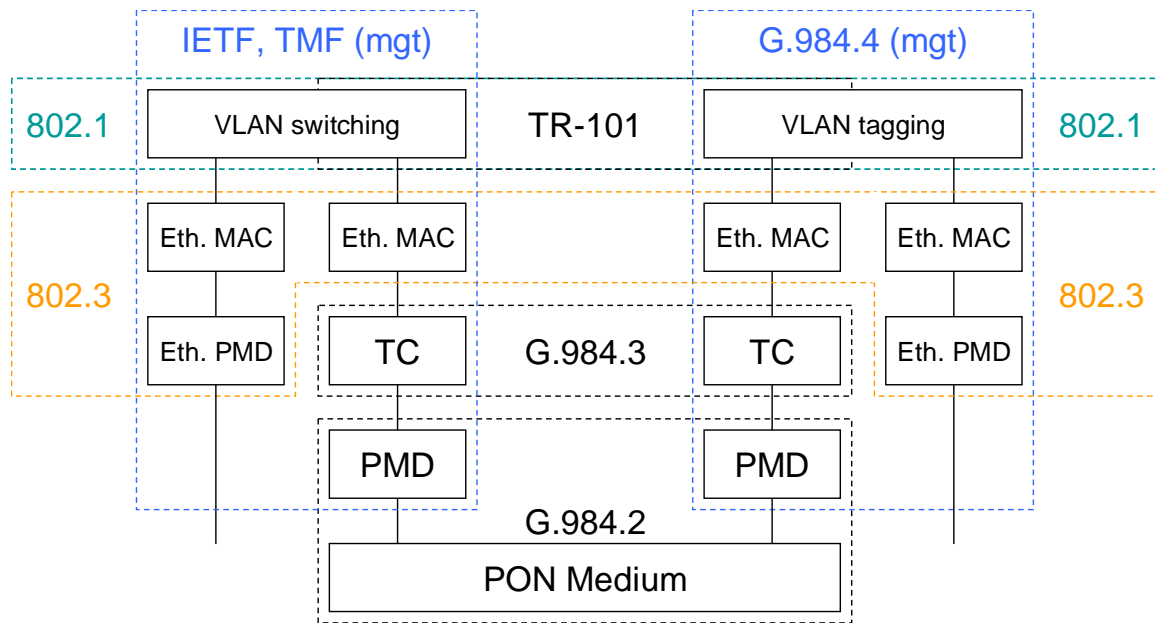
The layer diagram for Ethernet service is shown in Figure I.11. In the ONT, Ethernet frames as defined in [b-IEEE 802.3] are extracted from the TC layer. In some ONTs, the Ethernet layer is quite abbreviated and little processing is done on the frames from their reception on the GPON interface to their transmission on the UNI. In other ONTs, true bridging is performed, with MAC address processing and potentially more. In some cases, PPPoE (not shown) is supported; however, this scheme seems to be waning.

In some ONTs, some sort of VLAN processing is done, as defined in the IEEE 802.1-series of standards. Most systems use the 802.1ad version, where two layers of tags have been specified, although some systems actually support up to four layers of tags to be applied. This typically involves adding tag(s) in the upstream, and removing tag(s) in the downstream, for the purpose of identifying each user/service packet via their VLAN-ID. However, this is not necessary in all cases, since the PON itself has the GEM port-ID mechanism for such identification.

On the OLT side, the Ethernet frames are taken from the GPON, and in some cases they receive their VLAN tags at the OLT (basically, swapping the GEM port-ID for an Ethernet VLAN tag). Then, in nearly all equipment, the resulting frames are switched using an Ethernet switching matrix. This switching can be on the basis of VLAN tags, or MAC addresses, or both. There are several mainstream arrangements of VLANs; these are specified in [b-DSL TR-101]. The traffic then leaves the OLT over some type of Ethernet interface, for connection to an edge routing device or other Ethernet aggregation device.

It should be noted that there are several different interfaces that can take the place of an Ethernet Phy. These include xDSL (e.g., see below), MoCA, HPNA, HPNA-over-coax, 802.11 Wi-Fi, and perhaps others yet to be devised. However, due to Ethernet's pervasive nature, all of these alternative PHYs are defined so that they operate in a way nearly the same as Ethernet, and so their impact on the GPON system is rather small.

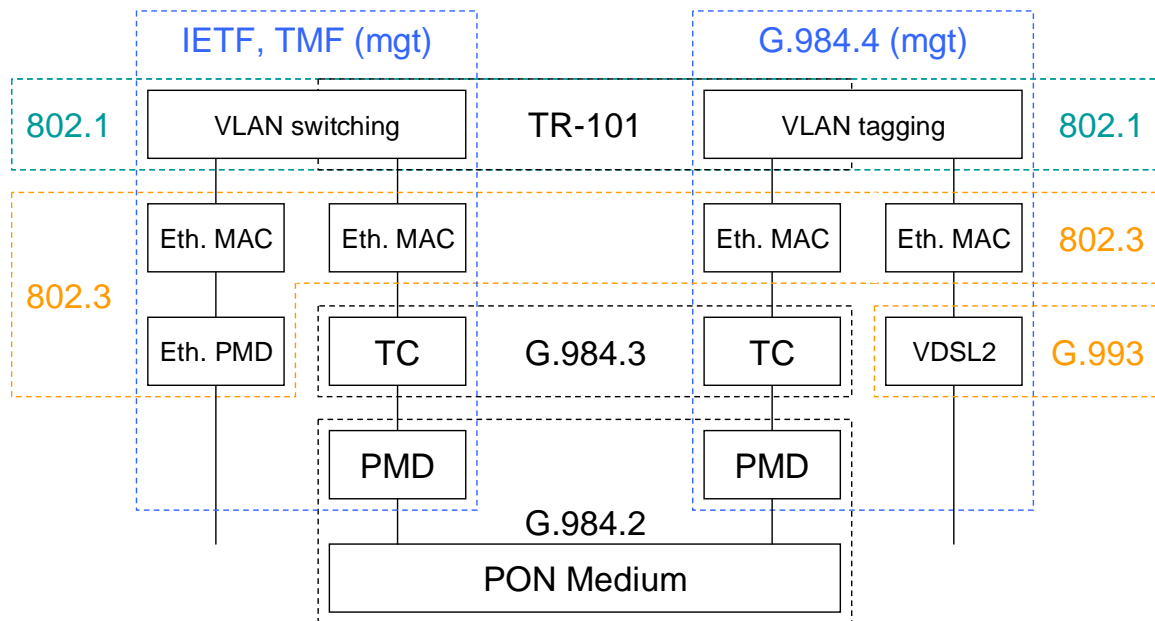
All of these ONT features are controlled via the OMCI, as defined in [ITU-T G.984.4].



**Figure I.11 – Ethernet data service**

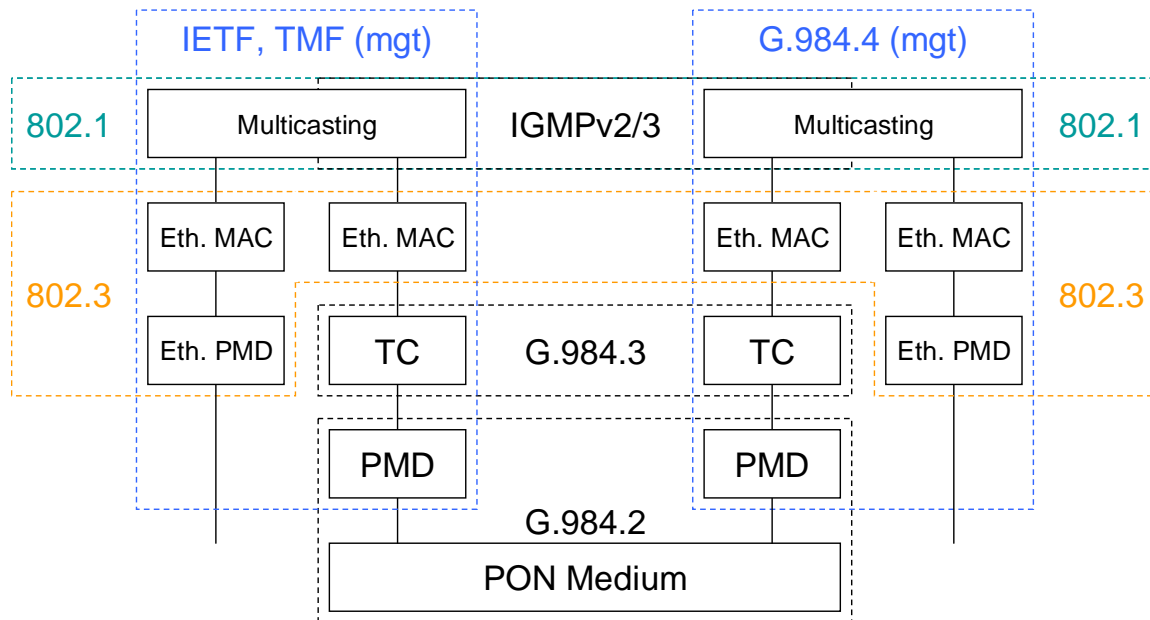
The VDSL2 service is shown in Figure I.12. The first thing to be said is that the DSL type that is most widely used for GPON is VDSL2 (defined in the ITU-T G.993-x series of Recommendations), using packet transport mode. It is possible that ADSL2 plus or VDSL1 might be implemented for compatibility reasons, however, it is not the main thrust of most GPON development. With this said, the VDSL2 VTU-O function in the ONT operates much like an Ethernet PHY, and most of the layer diagram is similar to that of an Ethernet service. There are important differences, the biggest of which is the presence of multiple bearer channels in the same port. Each of these bearers would be treated as a 'virtual PHY', and the overall system is still unchanged.

The management of the VTU-O located in the ONT is described in [ITU-T G.984.4].



**Figure I.12 – VDSL2 service**

Figure I.13 describes the multicast service. This is really a logical service, usually provided in conjunction with an Ethernet UNI (or similar). However, it has an impact on the GPON system, so we include it here. The multicasting interactive signalling is provided by the IETF IGMP, versions 2 or 3. This IP-layer multicasting topology is typically translated into Ethernet-layer multicasting via the trivial mapping defined in IEEE 802.1 standards. The management of multicasting, including the eligibility of UNIs to receive multicast traffic, the GPON ports that contain the multicast traffic, and their interconnection, is defined in [ITU-T G.984.4].



**Figure I.13 – Multicast service**

### I.3.3 Voice functions

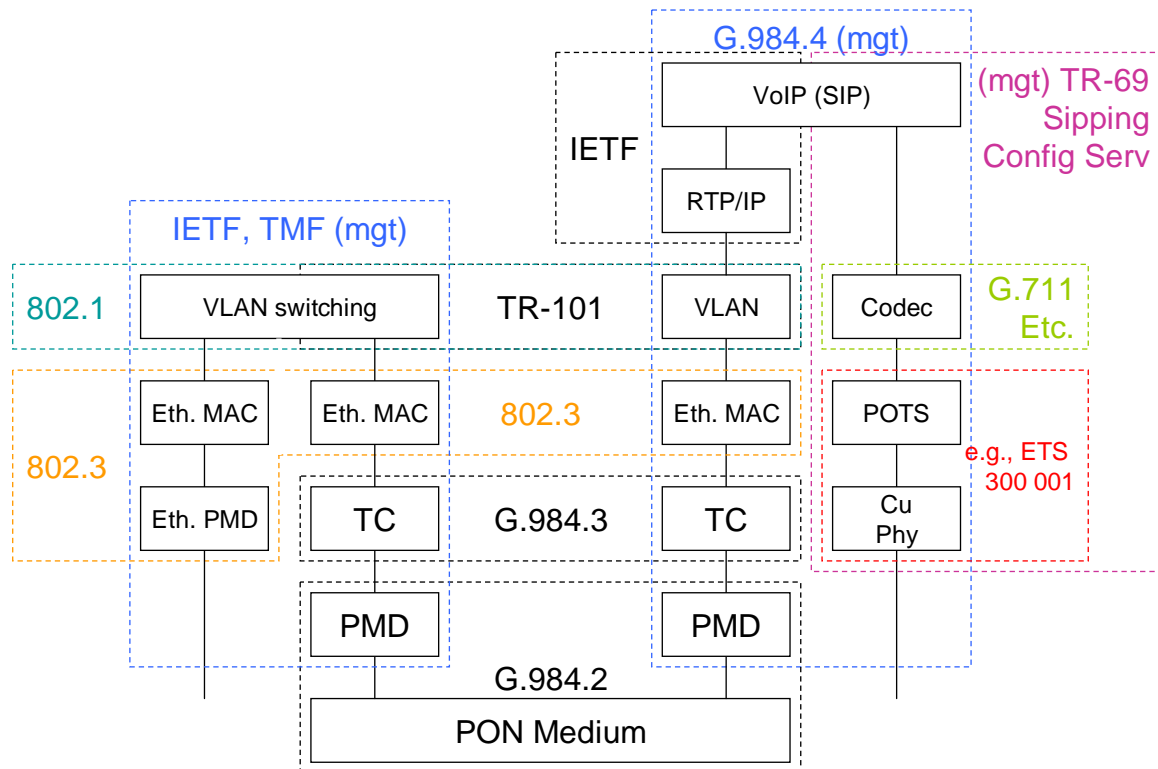
The packet-based voice service flow is pictured in Figure I.14. By packet voice service, we describe a voice service that does not terminate on a class 5 TDM switch but instead is transported via an IP network to its destination. The mainstream protocol system used in this scenario is SIP, running over RTP/UDP/IP, all defined in IETF documents. This is easy to say, but because SIP-based VoIP aims to replace the class 5 switching system, it must therefore implement the sizable set of voice service features. A great deal of interoperability engineering must be done in any combination of VoIP-ONT and softswitch.

The voice codecs are defined in the [b-ITU-T G.711], [b-ITU-T G.729], [b-ITU-T G.726], [b-ITU-T G.723] family. It should be noted that while the majority of VoIP systems are actively exploring advanced codecs for compression reasons, GPON is not concerned with this, since bandwidth is plentiful. In contrast, the codec selection here is mainly driven by interoperability with the far end of the SIP VoIP session.

The POTS UNI is defined for the large part by national standards (e.g., European operators use [b-ETSI ETS 300 001]). However, it must be noted that POTS remains a very intricate service, and many operators have special requirements on the POTS interface, particularly on the lowest-level mechanical and electrical specifications of the metallic interface.

From the SIP agent in the ONT, the service flow traverses a path very similar to the standard Ethernet service. VLAN tagging and Ethernet bridging may be applied at either the ONT, or OLT, or both. The user traffic, both bearer and signalling, leaves the OLT via an Ethernet interface, usually shared with other services.

The management of the packet voice service is varied at present. [ITU-T G.984.4] provides a full fault, configuration, accounting, performance-monitoring and security (FCAPS) support of SIP VoIP. However, there are several other in-band systems that are in use, such as TR-69, IETF sipping, and various proprietary configuration servers. These in-band systems are good in that they can manage VoIP terminal adapters anywhere on a network, so they have a wide reach. However, most suffer from poor practical standardization, and a lack of interactive features (such as the support of alarms and performance management). To help address this last point, even when an in-band system is used for configuration of VoIP, the OMCI can still be used to gather alarms and PM information. This is basically a mixed management system.



**Figure I.14 – Packet voice service**

The protocol stack diagram for circuit-switched voice service is shown in Figure I.15. In this scenario, VoIP is being used to transport the voice signals from the ONT to the class 5 TDM switch in the central office, and no further. The protocol used in this case is usually H.248, since this system is suited to voice gateway interfaces, of which the ONT and OLT each have one.

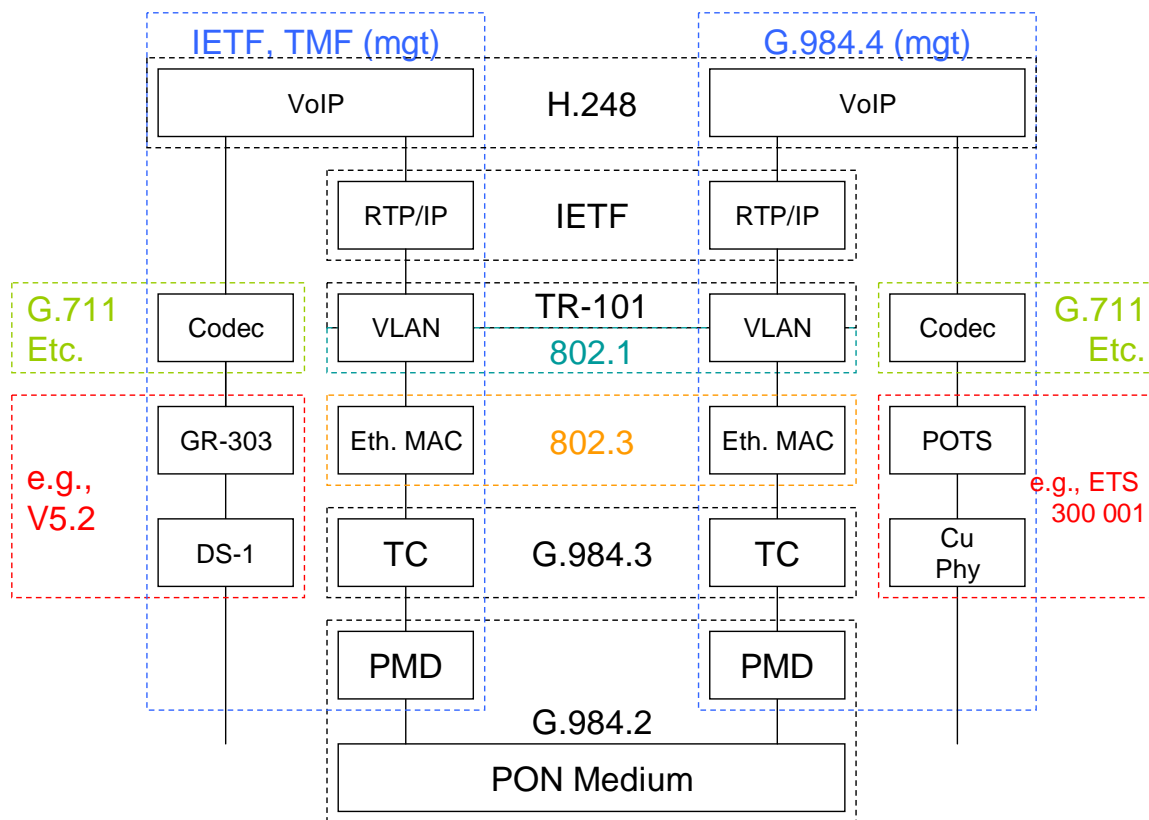
At the ONT, from the codec and below, the arrangement is exactly the same as in the packet voice case.

At the OLT, the H.248 flow is terminated, usually in a special-purpose voice gateway module. This module's function is to regenerate the customer's voice interface, and format the data representing that interface in the way that a conventional DLC system would, as defined by the appropriate regional standard (e.g., V5.2). This interface, most commonly carried physically by DS1 or E1 interfaces, can then be tied directly into a class 5 switch with integrated DLC interfaces. The whole intent is to minimize the impact of the GPON deployment on the normal operation of voice services in the CO.

The management of this kind of VoIP also has the potential for standard overlap, since all the options are available for H.248 ONTs. However, the OMCI method is used quite often in this case, since the advantages of the in-band system all but disappear for this scenario. The OMCI is a

self-contained solution for the management of voice services on GPON, and seems an easy choice in this scenario.

There are additional combinations of transport protocols, functional architectures and management protocols that are possible. The intent of the two illustrations here is to highlight the most active combinations.



**Figure I.15 – Circuit-switched voice service**

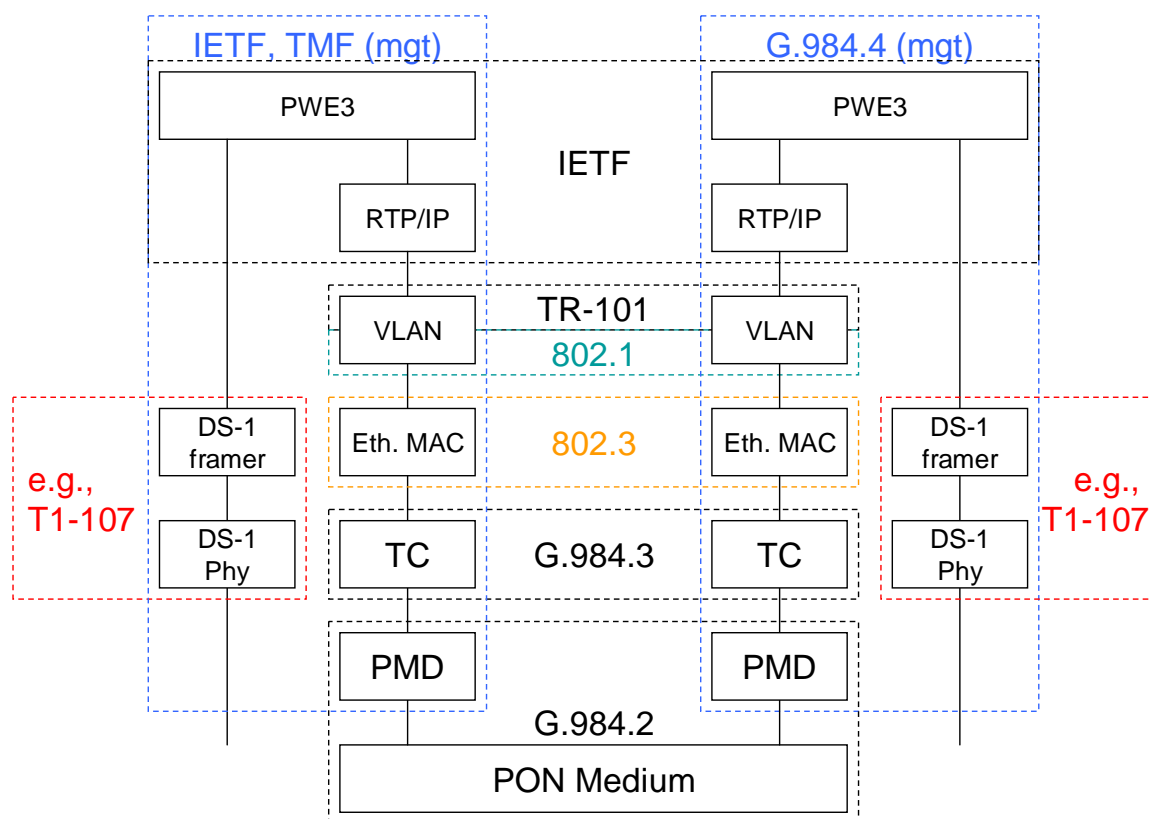
### I.3.4 Circuit emulation functions

TDM interfaces can also be supported over packet transport on GPON, as shown in Figures I.16 and I.17 (note the DS-01/E1 Framer would not be required for a transparent T1/E1 service). There are several options that can be exercised here. The first involves the transport of the actual TDM payload, using either a variant of the IETF PWE3 system of protocols (shown above), or the Metro Ethernet forum's MEF 8 protocol. The second involves the use of a local OLT TDM interface (shown above) or the use of a packet interface on the OLT leading to a gateway somewhere else in the network. This would seem to present quite a large set of alternatives, but in practice it has turned out not to be a big issue because most hardware supports nearly all of the options. So, interoperability is mostly a matter of negotiating the transport protocol. Circuit emulation may also require a network clock to be delivered to the PWE3 interworking functions. Differential timing mode supports better jitter/wander performance than adaptive mode.

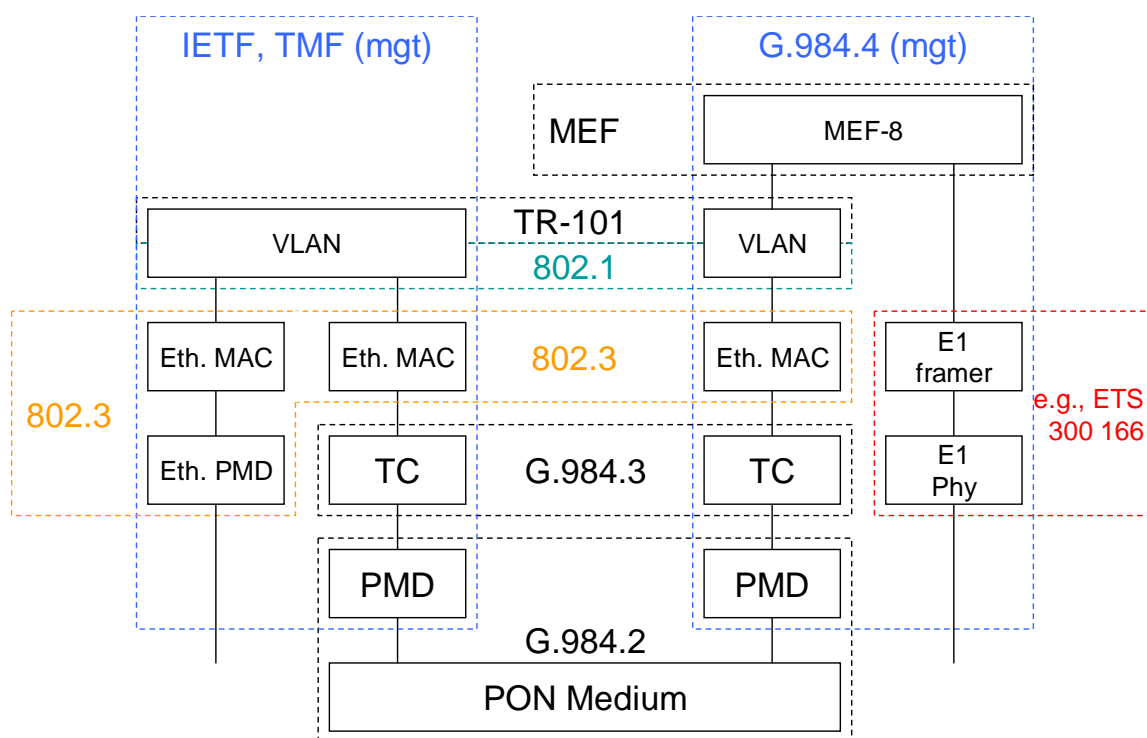
The GPON core, up to and including the VLAN layer is the same as in the typical Ethernet service.

The actual TDM interfaces are defined in, for example, [b-ITU-T G.703] for DS1 and E1 interfaces, or the appropriate regional standard (e.g., [b-ATIS T1-107] for DS1 interfaces, [b-ETSI ETS 300 166] for E1 interfaces).

The management of either PWE3 or MEF 8 interworking is described in [ITU-T G.984.4].



**Figure I.16 – Packet TDM service using PWE3 and grooming OLT**

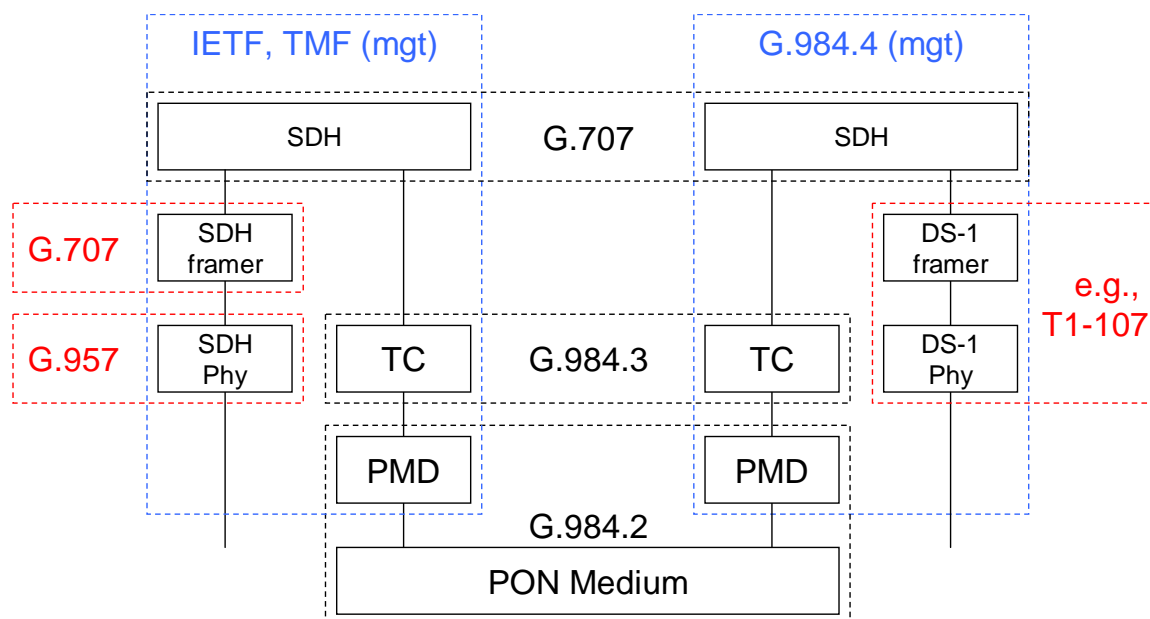


**Figure I.17 – Packet TDM service using MEF 8 and pure OLT**



Figure I.18 shows an alternative for TDM service transport within the GPON system. This scheme transports SDH tributary units over GEM ports directly. The definition of the format of the encapsulated data is defined in [b-ITU-T G.707]. This scheme is mainly applicable where the TDM service will be terminated at the OLT and transported in an SDH interface, as shown.

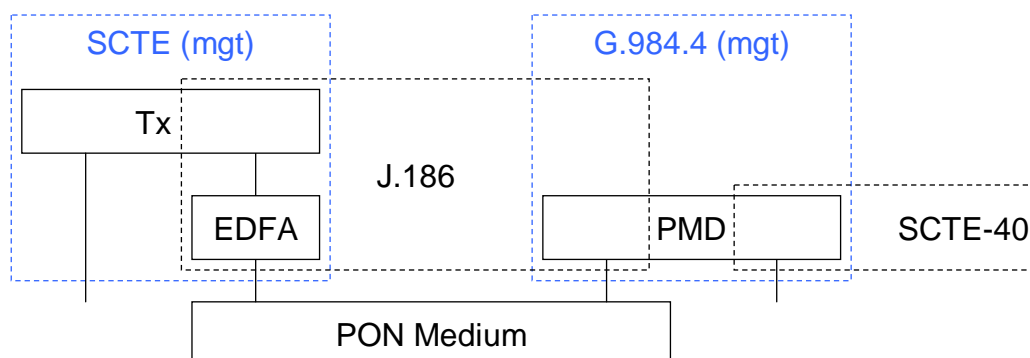
The management of this method at the ONT is through the OMCI ([ITU-T G.984.4]).



**Figure I.18 – Circuit TDM service**

### I.3.5 Video overlay functions

Figure I.19 shows the video overlay service. This is carried on the PON using a third wavelength, and is practically distinct from the other services. The signal format delivered to the customer is defined by SCTE standards, and the management of the ONT interface is given by [ITU-T G.984.4]. The optical interfaces throughout the rest of the service path are generally defined by [b-ITU-T J.186]. In practice, the details of the video OLT and subtending optical amplifiers are left to network operator engineering, especially the signal levels at each point in the network. This is due to the large variations in network physical topology and channel plans.



**Figure I.19 – Video overlay service**

## **Appendix II**

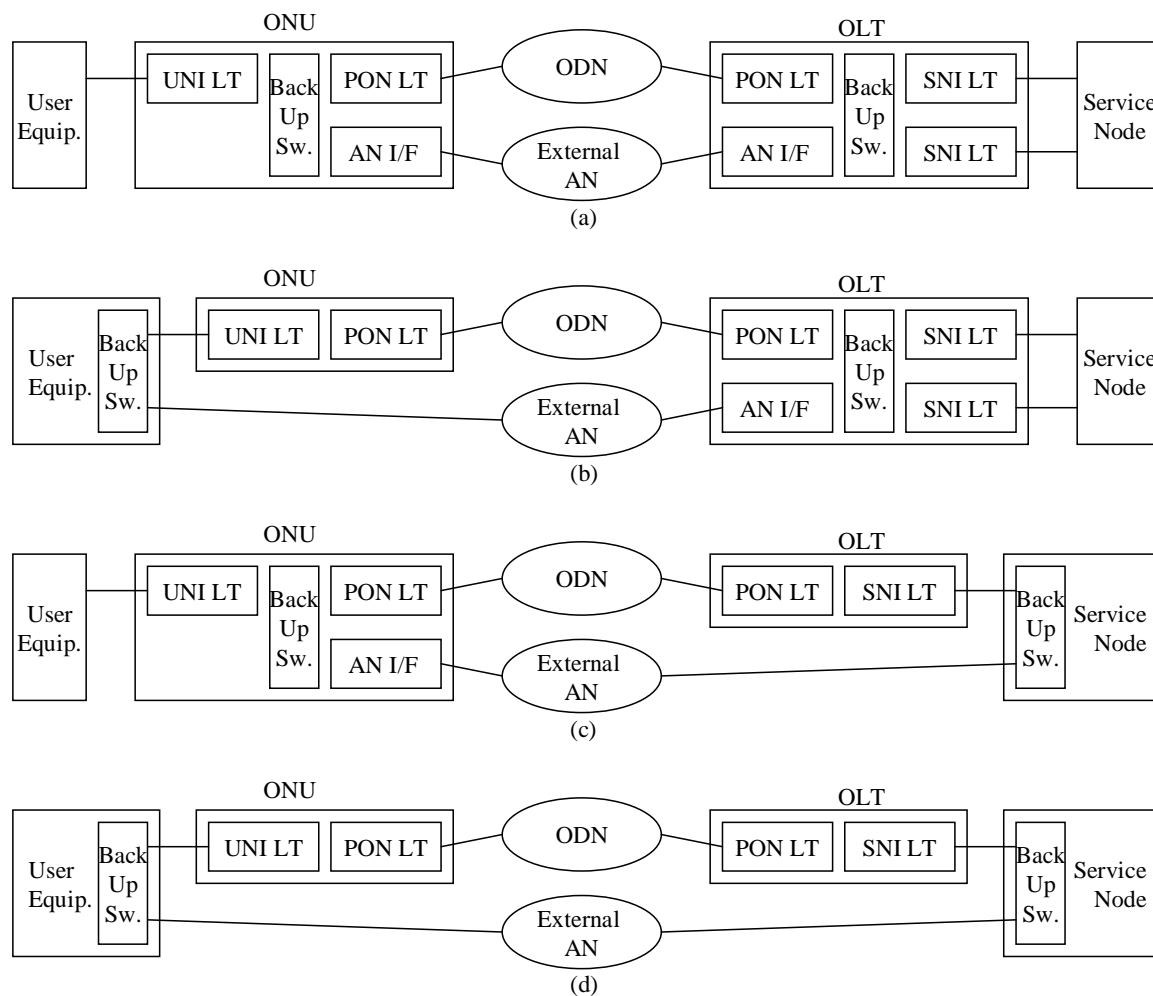
### **External access network backup**

(This appendix does not form an integral part of this Recommendation)

In many applications, some resilience to faults in the optical access network is desired, but the cost of full protection as described in clause 14 is not supportable. In these cases, a cost-effective alternative is to provide a lower capacity backup to the service via an external access network. Examples of the external access network include digital subscriber line, fixed wireless, mobile wireless, or hybrid fibre-coax networks.

Because of the wide range of backup access networks, the interface from the PON equipment to the backup network has to be at the data frame networking layer, described in the IEEE 802.1 standards. By abstracting the interface to this layer, the PON equipment need not worry about the details of the backup network (nor does the backup network need to worry about the PON).

The key aspect of such external backup is the location and control of the backup switching logic. Because of the widely disparate capacities of the primary PON and the backup network, it does not make sense to send two copies of traffic at all times. Also, due to the packet-nature of the traffic, it is difficult for the receiver to resolve multiple copies of the same packets. It is assumed that the receiver will simply accept all packets arriving from either access network; therefore, it is important to only send one copy of any packet. Therefore, the source side must direct the traffic to the appropriate access network, and it must have the information required to make the correct choice. In addition, the source side switching equipment must also have the ability to prioritize traffic and selectively discard traffic that exceeds the capacity of the backup network when backup is in force. In the upstream, the backup switch can be located in the ONU or beyond the UNI. In the downstream direction, the backup switch can be located in the OLT or beyond the SNI. These arrangements are illustrated in Figure II.1.



**Figure II.1 – The four switching arrangements for external access network backup**

In option a), the switches are both located in the PON equipment. It is assumed that the PON equipment has knowledge of the PON link's operational state, and therefore it can direct traffic to the PON interface if it is working correctly and to the backup network interface if it is not. Therefore, no additional signalling is required. The configuration of the ONU's dual ANIs must be supported in the OMCI.

In option b), the upstream switch is located beyond the ONT's UNI. A typical situation would be for this function to be located in an Ethernet switch or IP router. Therefore, that switch must be capable of learning the status of the ONU's PON link via some form of signalling. This could be as crude as the ONU deactivating the UNI when the PON link has failed, to some more sophisticated Ethernet alarm indication signal (AIS) such as described in [b-ITU-T Y.1731]. The downstream switch is internally controlled within the OLT.

In option c), the downstream switch is located beyond the OLT's SNI. A typical function would be for this function to be located in an Ethernet aggregation network or service edge router. Just as in option b), this switching logic must be given the information on the status of the PON link to the ONT in question. Unlike the previous case, however, a sophisticated per-ONT AIS scheme must be employed since the SNI is shared over many ONUs, some of which may not have a PON transmission problem. This could be the AIS as described in [b-ITU-T Y.1731], but applied on a per-VLAN basis. The upstream switch is internally controlled within the ONU, with the configuration of the ONU's dual ANIs being supported in the OMCI.

In option d), both of the switches are located beyond the PON equipment. This scheme is most distantly removed from the access networks, since all the backup switching/routing is happening in other equipment. This raises the possibility of allowing the backup to occur using the more autonomous schemes such as Ethernet spanning tree or IP routing. In either case, the backup link would need to be configured as the 'expensive link', so that it would not be used if the PON link was available. These Layer 2 or 3 schemes tend to take longer than more direct schemes mentioned in the previous options a-c. Their performance could be improved by implementing the direct AIS schemes to provide a faster feedback into their control algorithms.

## Appendix III

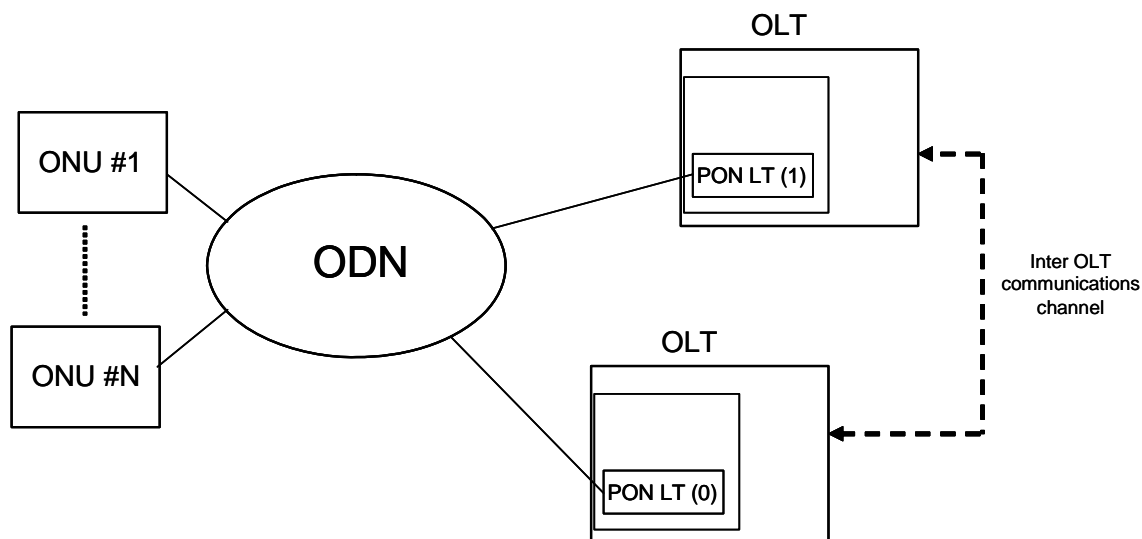
### Dual-parenting resilience

(This appendix does not form an integral part of this Recommendation)

Dual-parenting resilience refers to a system where PON protection is implemented using two OLT line terminations that are provided in two separate OLT equipment, typically in physically diverse locations. Such a scheme offers protection from catastrophic failure of the OLT equipment, its power supply, and the physical locality where it is placed.

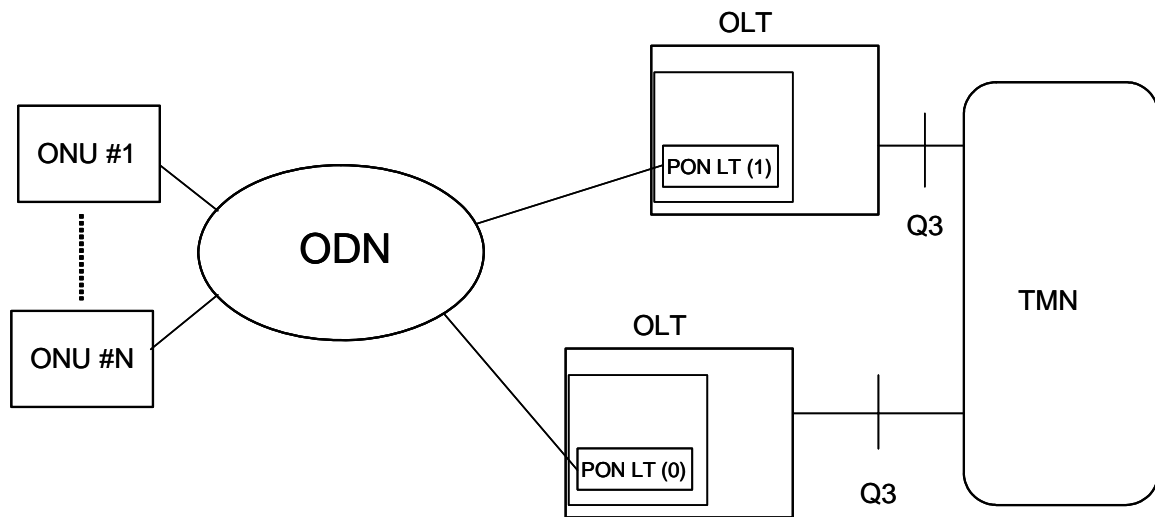
Unlike traditional PON protection, where both PON sections terminated in the same equipment, dual parenting requires coordination of the functions of two PONs in separate equipment. The prerequisite to accomplish this is that the ONUs being protected must be registered on both the working and remote OLTs. In this way, the logical state of the working OLT can be reproduced in the protection OLT with a minimum of delay. In addition, the protection switching of traffic upstream from both OLTs must also be supported. This topic is for future study, and is out of the scope of this discussion.

In dual-parenting type B protection, shown in Figure III.1, the main functionality to implement resilience resides within the OLT. This scheme requires the protection OLT to be in standby state, therefore it is necessary to synchronize the operation status of both OLTs. Additionally, a data communications channel is necessary between the two OLTs for sharing the service configuration of all ONUs that is needed to re-establish the connections between all UNIs and SNIs at the remote OLT (Figure III.1).



**Figure III.1 – Diagram showing a communications channel between working and remote standby OLTs**

The data communications channel between the two OLTs can be implemented in different ways. One straightforward method is using the management plane at either the element management layer or network management layer (Figure III.2).



**Figure III.2 – Inter-OLT communications channel established through management plane**

The events that trigger dual-parenting switching are:

- 1) Fibre cut in the ODN on the working OLT side.
- 2) Degraded link.
- 3) Failure of the PON LT in the OLT.
- 4) OLT failure.

The standby remote OLT could be triggered (enabled) after asserting PON LT LOS and a second check via inter-OLT communications channel. A dying gasp message from all ONUs should prevent dual-parenting switch-over.

The remote standby OLT should maintain, as a minimum, the serial number list of registered ONUs and the service profile of each ONU. Optionally, other data are also possible to be shared between working and remote OLT in order to speed up service recovery.

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